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(54) **PROGRAMMABLE SYMBOLIC EXECUTION BASED DYNAMIC CHECKER**

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G06F 11/34	(2006.01)

(52) **U.S. Cl.**

CPC ***G06F 11/3604*** (2013.01); ***G06F 11/3466*** (2013.01); *G06F 8/47* (2013.01); *G06F 8/52* (2013.01)

(58) **Field of Classification Search**

CPC G06F 8/47; G06F 8/52; G06F 8/443; G06F 11/3466; G06F 2201/865; G06F 9/45504; G06F 9/45516

See application file for complete search history.

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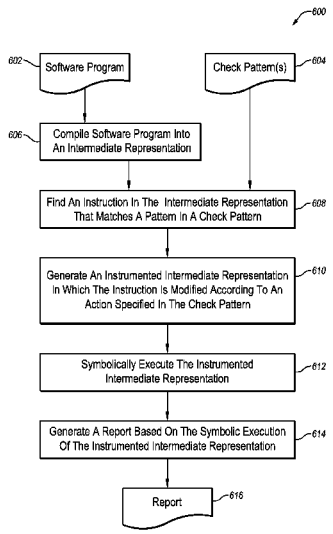
(57) **ABSTRACT**

A method of analyzing a software program includes compiling the software program into an intermediate representation. The method also includes finding an instruction in the intermediate representation that matches a pattern in a check pattern. The method also includes generating an instrumented intermediate representation in which the instruction is modified according to an action specified in the check pattern. The method also includes symbolically executing the instrumented intermediate representation.

16 Claims, 7 Drawing Sheets



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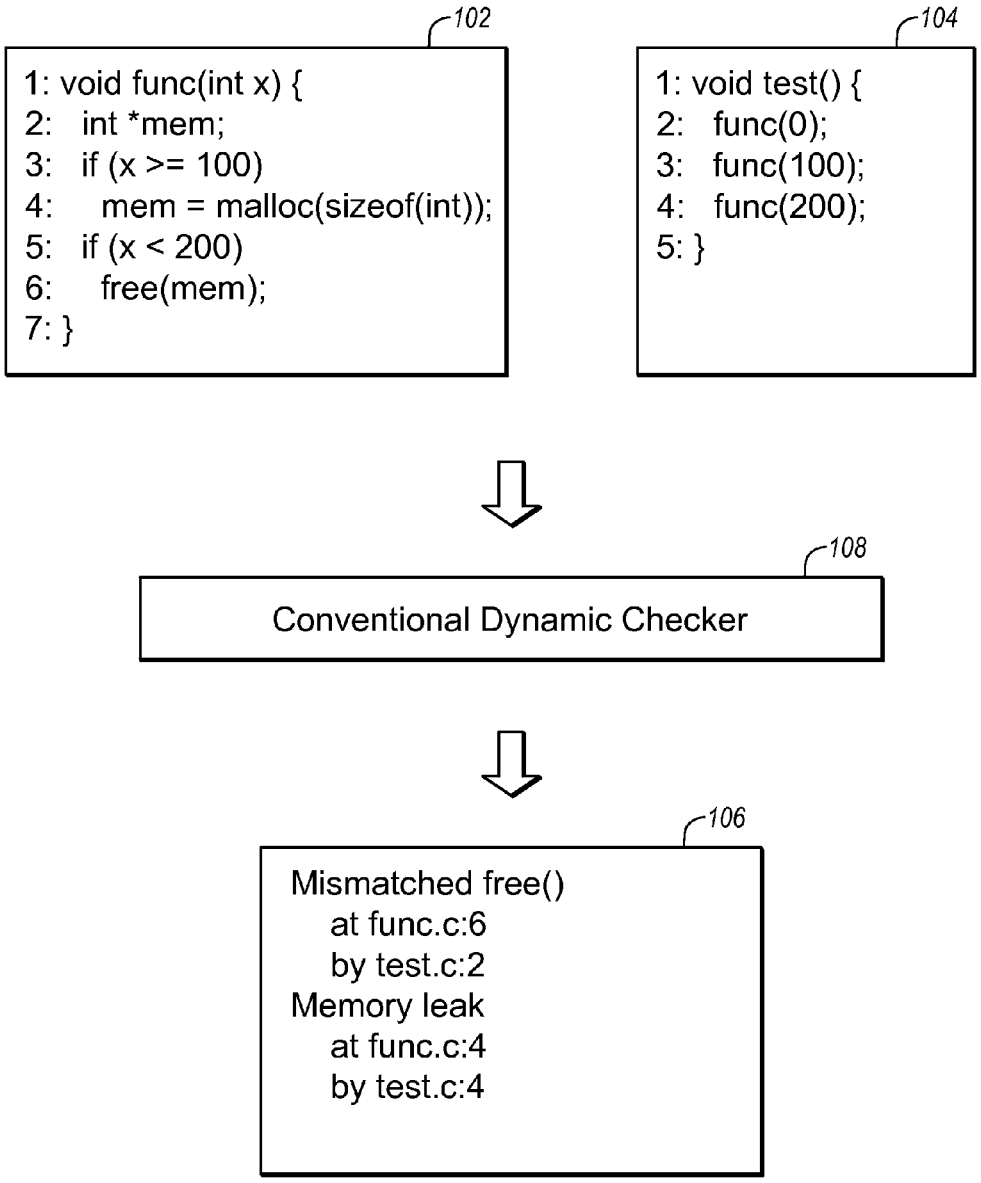


Fig. 1
Prior Art

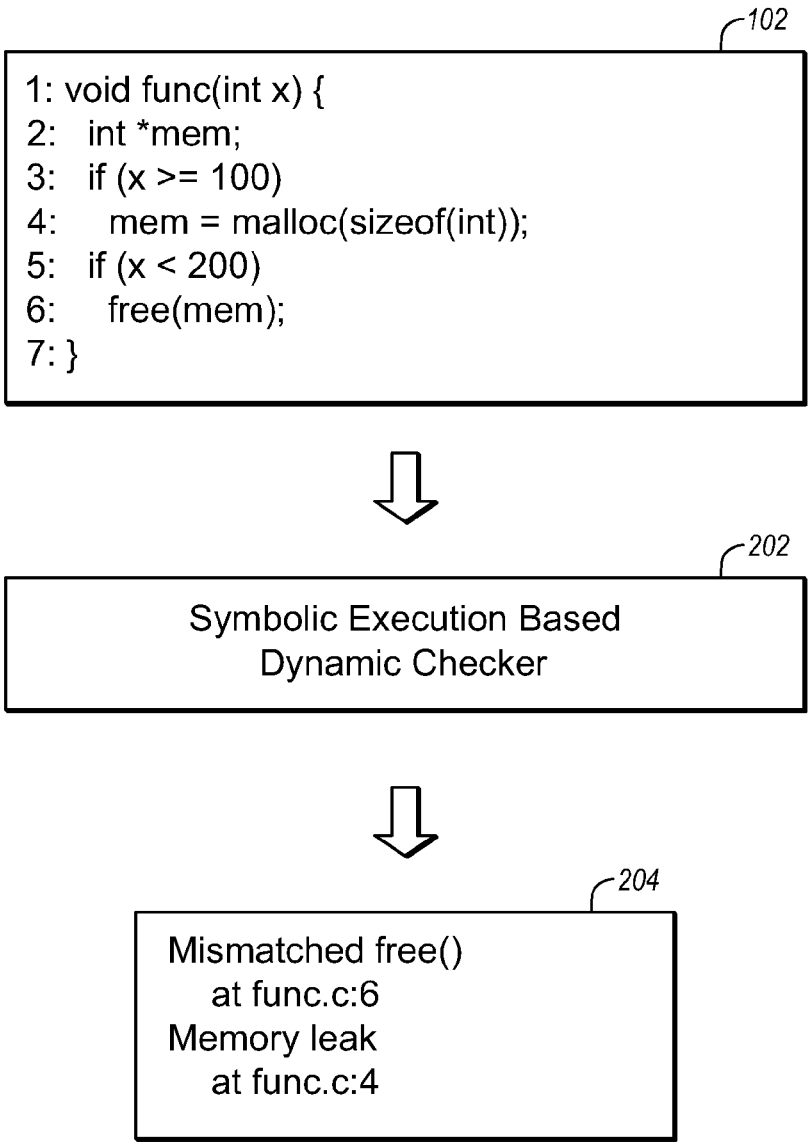

102
1: void func(int x) {
2: int *mem;
3: if (x >= 100)
4: mem = malloc(sizeof(int));
5: if (x < 200)
6: free(mem);
7: }
202
Symbolic Execution Based
Dynamic Checker
204
Mismatched free()
at func.c:6
Memory leak
at func.c:4

Fig. 2

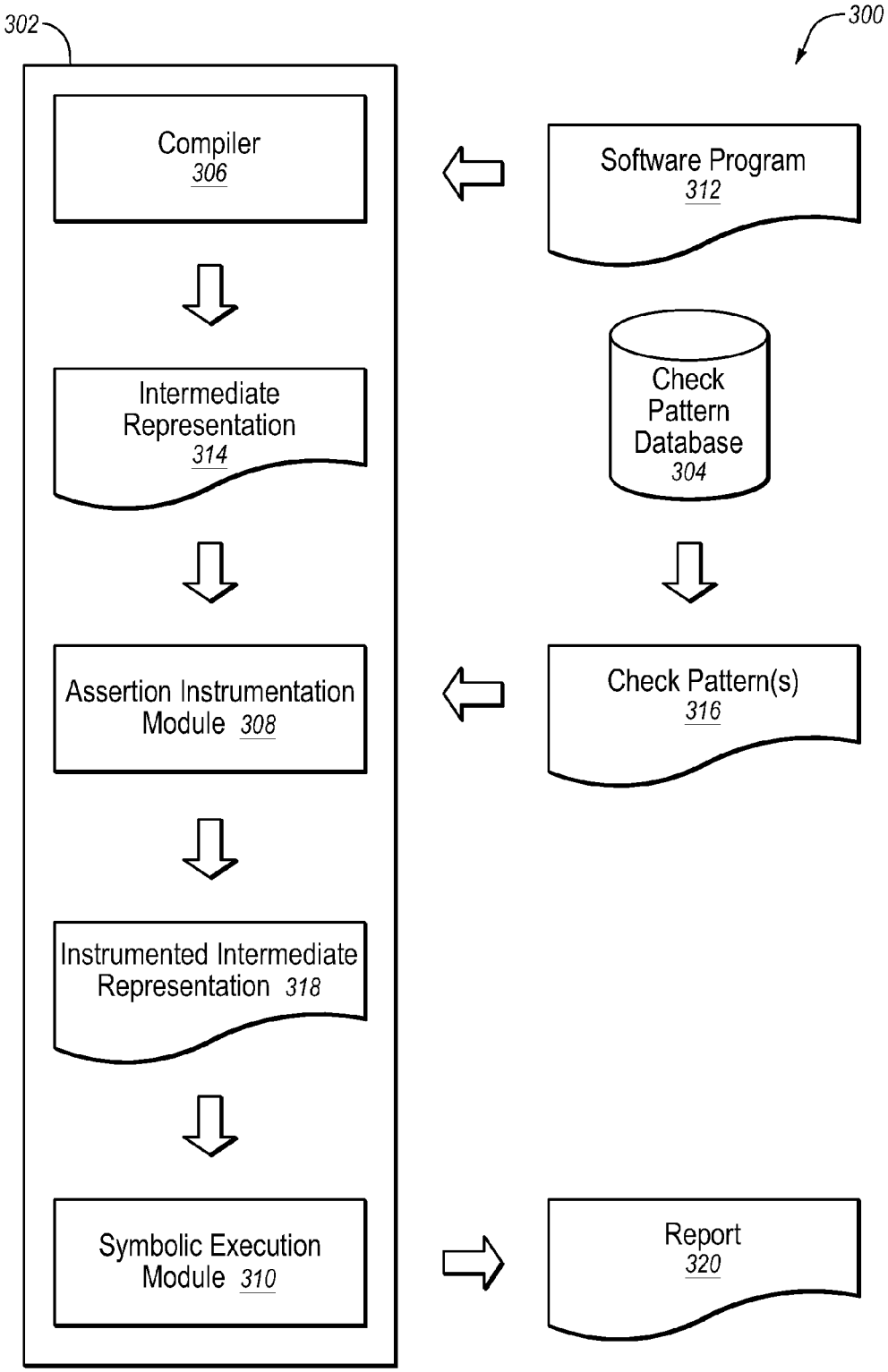

302
300
Compiler
306
Software Program
312
Intermediate
Representation
314
Check
Pattern
Database
304
Assertion Instrumentation
Module 308
Check Pattern(s)
316
Instrumented Intermediate
Representation 318
Symbolic Execution
Module 310
Report
320

Fig. 3

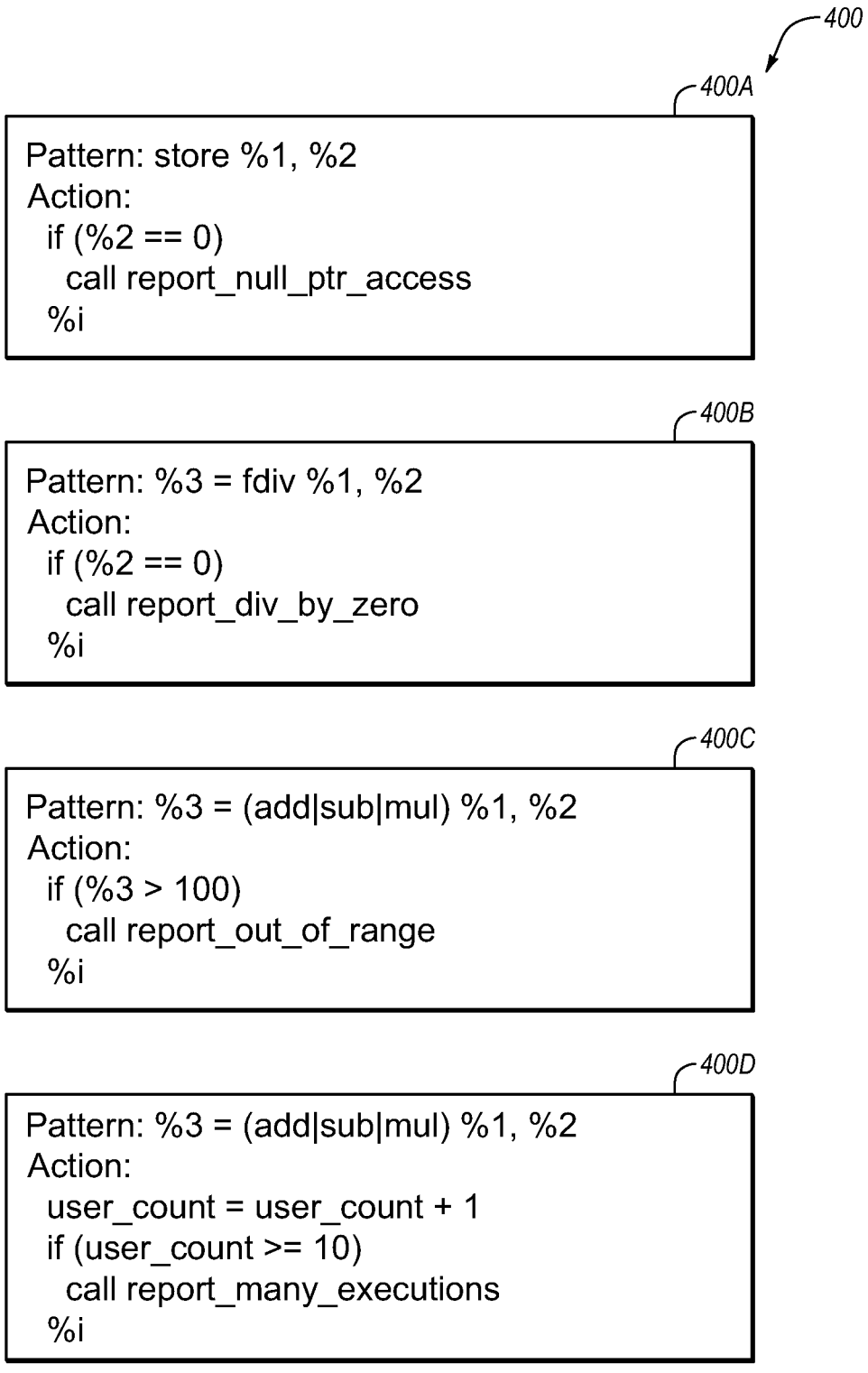

400
400A
Pattern: store %1, %2
Action:
if (%2 == 0)
call report_null_ptr_access
%i
400B
Pattern: %3 = fdiv %1, %2
Action:
if (%2 == 0)
call report_div_by_zero
%i
400C
Pattern: %3 = (add|sub|mul) %1, %2
Action:
if (%3 > 100)
call report_out_of_range
%i
400D
Pattern: %3 = (add|sub|mul) %1, %2
Action:
user_count = user_count + 1
if (user_count >= 10)
call report_many_executions
%i

Fig. 4

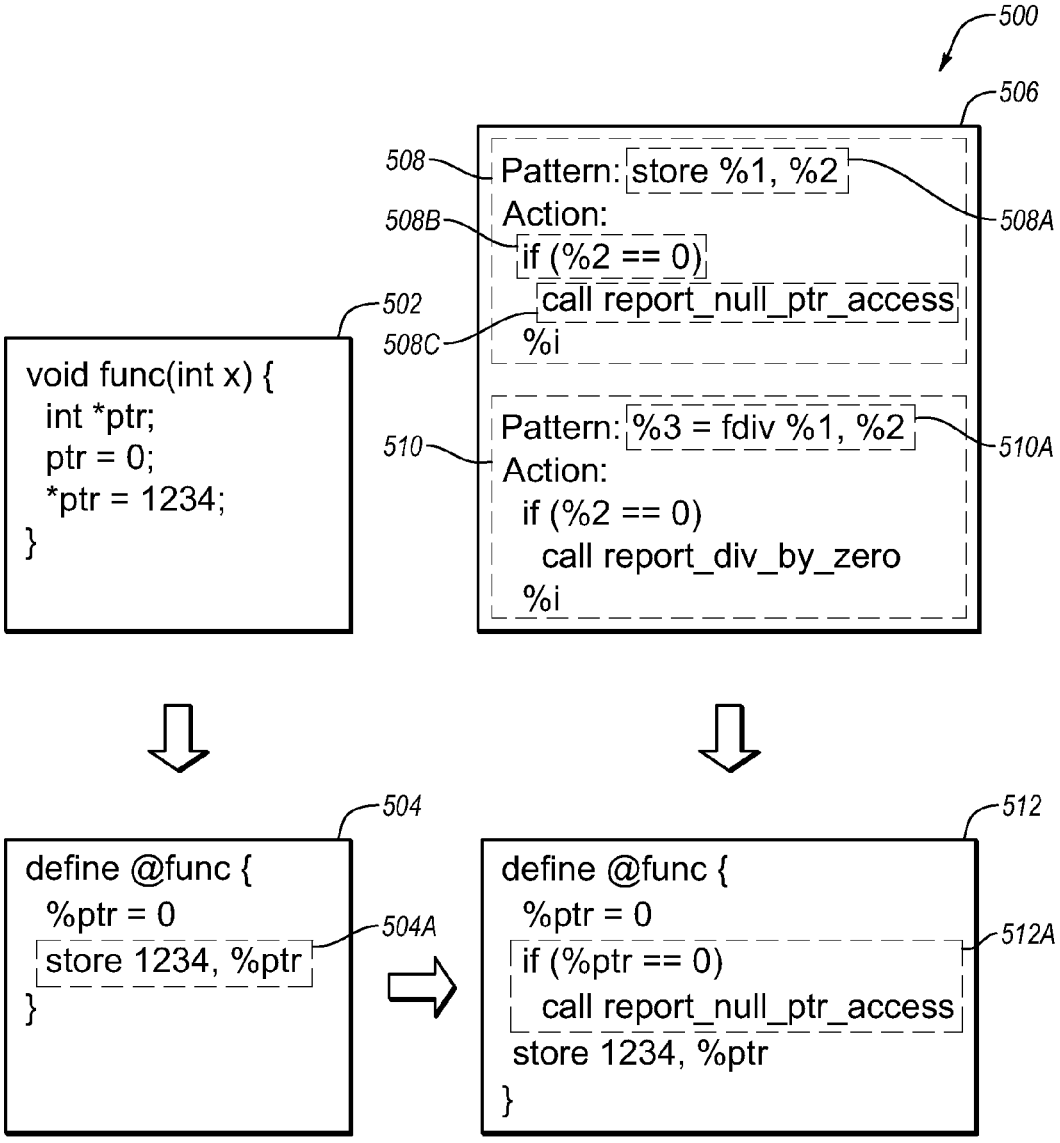

500
506
508
Pattern: store %1, %2
508A
Action:
508B
if (%2 == 0)
call report_null_ptr_access
%i
502
508C
void func(int x) {
int *ptr;
ptr = 0;
*ptr = 1234;
}
Pattern: %3 = fdiv %1, %2
510
510A
Action:
if (%2 == 0)
call report_div_by_zero
%i
504
define @func {
%ptr = 0
store 1234, %ptr
}
504A
512
define @func {
%ptr = 0
if (%ptr == 0)
call report_null_ptr_access
store 1234, %ptr
}
512A

Fig. 5

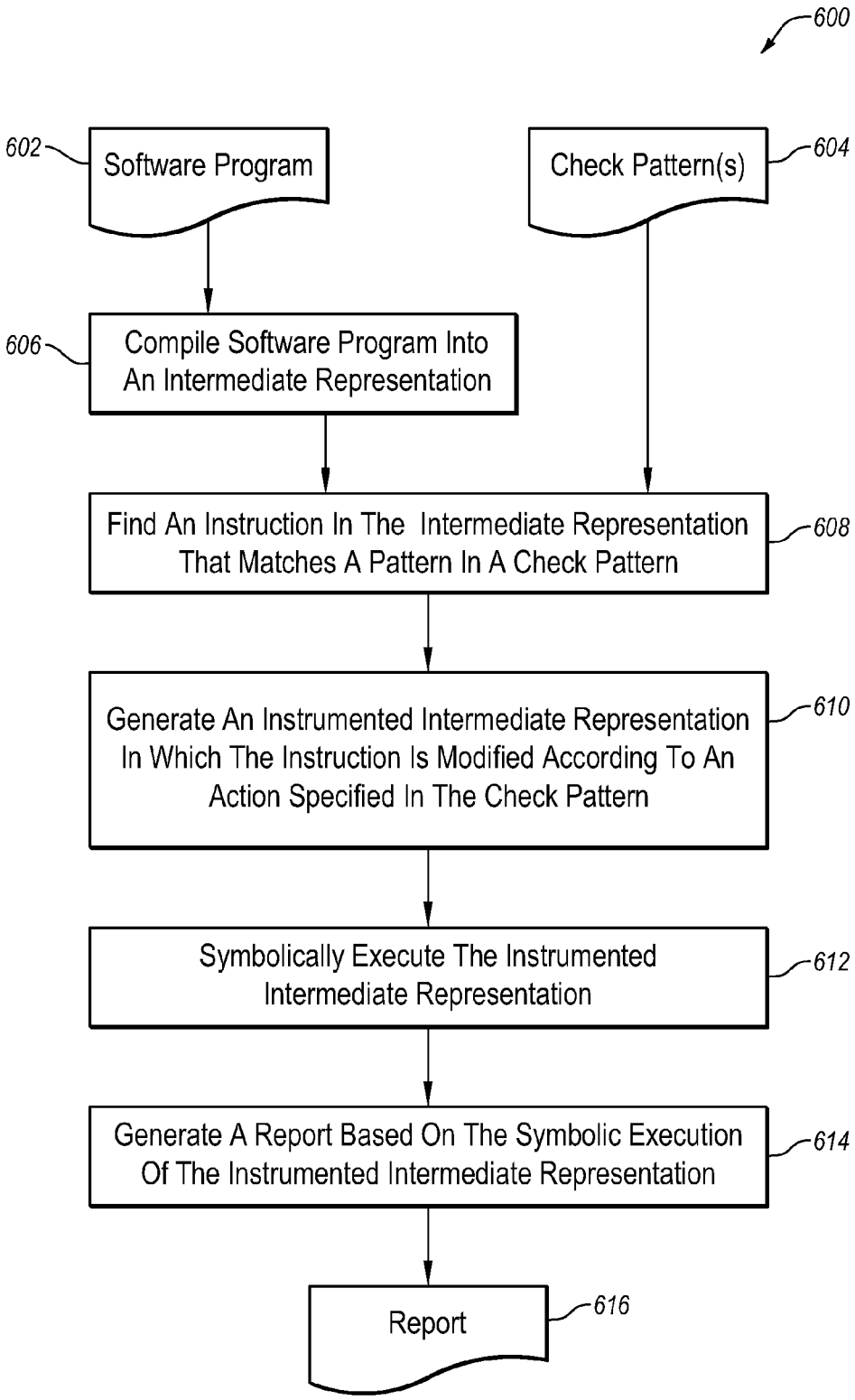
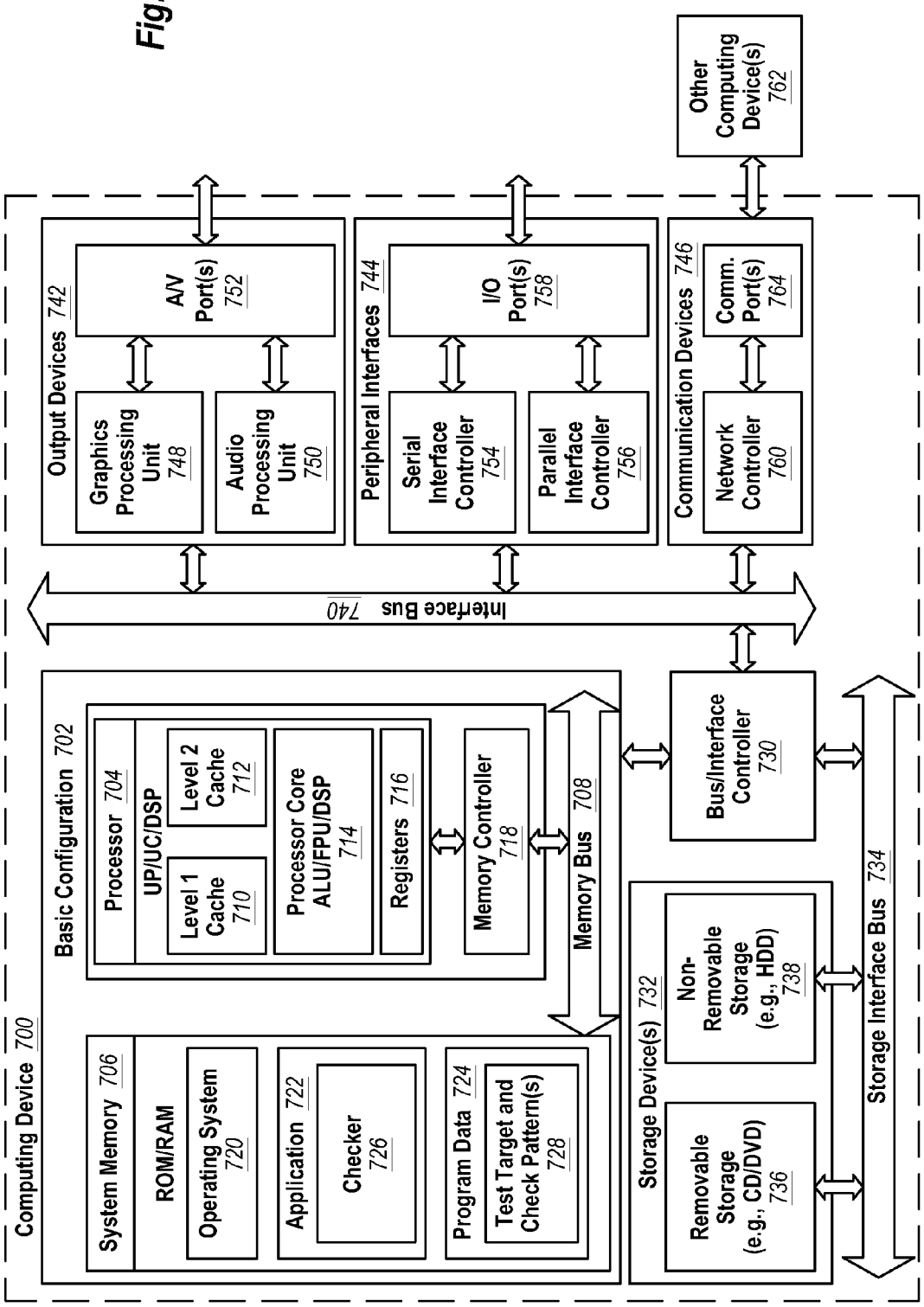

600
602
Software Program
604
Check Pattern(s)
606
Compile Software Program Into An Intermediate Representation
Find An Instruction In The Intermediate Representation That Matches A Pattern In A Check Pattern
608
Generate An Instrumented Intermediate Representation In Which The Instruction Is Modified According To An Action Specified In The Check Pattern
610
Symbolically Execute The Instrumented Intermediate Representation
612
Generate A Report Based On The Symbolic Execution Of The Instrumented Intermediate Representation
614
Report
616

Fig. 6

Fig. 7


Computing Device 700
Basic Configuration 702
Processor 704
UP/UC/DSP
Level 1 Cache 710
Level 2 Cache 712
Processor Core ALU/FPU/DSP 714
Registers 716
Memory Controller 718
Memory Bus 708
System Memory 706
ROM/RAM
Operating System 720
Application 722
Checker 726
Program Data 724
Test Target and Check Pattern(s) 728
Storage Device(s) 732
Removable Storage (e.g., CD/DVD) 736
Non-Removable Storage (e.g., HDD) 738
Storage Interface Bus 734
Bus/Interface Controller 730
Interface Bus 740
Output Devices 742
Graphics Processing Unit 748
Audio Processing Unit 750
A/V Port(s) 752
Peripheral Interfaces 744
Serial Interface Controller 754
Parallel Interface Controller 756
I/O Port(s) 758
Communication Devices 746
Network Controller 760
Comm. Port(s) 764
Other Computing Device(s) 762

PROGRAMMABLE SYMBOLIC EXECUTION BASED DYNAMIC CHECKER

FIELD

The embodiments discussed herein are related to a programmable symbolic execution based dynamic checker.

BACKGROUND

Dynamic checkers are used to check for the presence of various kinds of errors in software programs, such as assertion failures or violations, memory errors, and divide-by-zero errors to name a few. Examples of popular tools with dynamic checker functionality include some memory analyzers, profilers, and coverage analyzers.

In a typical implementation, a dynamic checker analyzes a software program by executing the software program using a test suite including one or more concrete inputs. The concrete inputs are identified and provided manually by a user. To detect errors, a user has to provide concrete inputs that trigger the errors. Accordingly, it is difficult to maintain a high-quality test suite which exercises sufficiently many paths in the software program and which catches corner-case bugs.

Symbolic execution is a technique for dynamically analyzing a software program. Symbolic execution uses as input values symbolic values instead of actual data and represents values of program variables as symbolic expressions. As a result, the outputs computed by a software program that is symbolically executed are expressed as a function of the symbolic inputs. Through symbolic execution, each path within a software program may be symbolically executed.

Some dynamic checkers implement symbolic execution, and may be referred to as symbolic execution based dynamic checkers. Conventional symbolic execution based dynamic checkers have limited defect detection, such as detection of simple memory errors including null pointer errors and out-of-bound access errors. Moreover, the detectable types of defects in conventional symbolic execution based dynamic checkers are hardcoded such that users are unable to easily change the types of defects that are detected.

The subject matter claimed herein is not limited to embodiments that solve any disadvantages or that operate only in environments such as those described above. Rather, this background is only provided to illustrate one example technology area where some embodiments described herein may be practiced.

SUMMARY

According to an aspect of an embodiment, a method of analyzing a software program includes compiling the software program into an intermediate representation. The method also includes finding an instruction in the intermediate representation that matches a pattern in a check pattern. The method also includes generating an instrumented intermediate representation in which the instruction is modified according to an action specified in the check pattern. The method also includes symbolically executing the instrumented intermediate representation.

The object and advantages of the embodiments will be realized and achieved at least by the elements, features, and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

Example embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. **1** illustrates an example function, a corresponding test function, and a corresponding error report generated by a conventional dynamic checker;

FIG. **2** illustrates the example function of FIG. **1** and a corresponding error report generated by a symbolic execution based dynamic checker;

FIG. **3** is a block diagram of an example system for analyzing software programs;

FIG. **4** illustrates various example check patterns that may be implemented in the system of FIG. **3**;

FIG. **5** schematically illustrates a process flow for analyzing software programs using a symbolic execution based dynamic checker;

FIG. **6** is a flowchart of an example method of analyzing a software program using a symbolic execution based dynamic checker; and

FIG. **7** is a block diagram illustrating an example computing device that is arranged for analyzing a software program using a symbolic execution based dynamic checker.

DESCRIPTION OF EMBODIMENTS

FIG. **1** illustrates an example function **102**, a corresponding test function **104**, and a corresponding error report **106** generated by a conventional dynamic checker **108**. In more detail, the example function **102** may be part of a software program that is being tested for errors and may be referred to as "func.c." A test suite (not shown) includes various concrete inputs manually provided by a user to test the function **102**. The test function **104** includes the concrete inputs including values of 0, 100, and 200 that are to be passed into the function **102** and may be referred to as "test.c." Because the function **102** includes two "if" statements, the test function **104** includes three concrete inputs to traverse all possible paths in the function **102**.

In operation, the conventional dynamic checker **108** executes the test function **104**, including calling the function **102** with each of the concrete inputs as arguments. When func(0) is called by the test function **104**, the first "if" statement at line 3 of the function **102** is skipped, and the second "if" statement at line 5 if the function is executed. Func(0) produces a memory error since execution of the second "if" statement without executing the first "if" statement frees unallocated memory. Accordingly, the conventional dynamic checker **108** generates the error report **106** identifying the error (e.g., "Mismatched free( )"), line 6 of the function **102** at which the error occurs (e.g., "at func.c:6"), and line 2 of the test function **104** that caused the error (e.g., "by test.c:2").

Func(100) and func(200) are also called by the test function **104**, and from the error report **106** it may be seen that func(200) results in a memory leak error.

As illustrated by the foregoing example, it takes three appropriately selected concrete inputs to execute all paths and catch the corner-case bugs of the relatively simple function **102**. Such concrete inputs are typically identified manually by a user, e.g., the programmer of the function **102**. For more complex functions and/or programs involving numerous functions, it may be complicated, time-consuming, and/or error-prone for the user to identify sufficient and appropriate concrete inputs to execute all paths and/or catch all corner-case bugs.

Accordingly, some embodiments discussed herein are related to a programmable symbolic execution based dynamic checker. In some embodiments, the programmable symbolic execution based dynamic checker may be configured to analyze software programs without providing concrete inputs, thereby eliminating the time and effort involved in manually identifying concrete inputs and improving the likelihood that all errors will be identified.

Embodiments of the present invention will be explained with reference to the accompanying drawings.

FIG. **2** illustrates the example function **102** of FIG. **1** and a corresponding error report **204** generated by a symbolic execution based dynamic checker **202** (hereinafter "checker **202**"), arranged in accordance with at least one embodiment described herein. In general, the checker **202** may be configured to instrument a target program, e.g., the function **102**, by inserting assertions according to one or more patterns, which may include default patterns and/or patterns specified by users. In some embodiments, the instrumentation is performed on an intermediate representation of the target program, such as a compiled version of the target program. Accordingly, the instrumentation may be language-independent.

In an example embodiment, for instance, the checker **202** may compile the function **102**, or a software program including the function **102**, into an intermediate representation. The checker **202** may search for and find instructions in the intermediate representation that match patterns in corresponding check patterns. The checker **202** may generate an instrumented intermediate representation in which the matched instructions are modified according to actions specified in the corresponding check patterns. For example, the instructions may be replaced by replacement instructions that include calls to corresponding error reports as described in more detail below. The checker **202** may then symbolically execute the instrumented intermediate representation and may generate a report, such as the error report **204**, that indicates one or more errors within the function **102**, or more generally within the corresponding software program.

FIG. **3** is a block diagram of an example system **300** for analyzing software programs, arranged in accordance with at least one embodiment described herein. The system **300** may be included in and/or may operate with a software editor to analyze software programs as described herein. The system **300** includes a symbolic execution based dynamic checker **302** (hereinafter "checker **302**") and a check pattern database **304**. The checker **302** is an example embodiment of the checker **202** of FIG. **2**.

The checker **302** may include a compiler **306**, an assertion instrumentation module **308**, and a symbolic execution module **310**. The checker **302**, including the compiler **306**, the assertion instrumentation module **308**, and the symbolic execution module **310** may be implemented in software, hardware, or any combination thereof. In an example embodiment, the compiler **306**, the assertion instrumentation module **308**, and the symbolic execution module **310** are implemented as computer instructions stored on a non-transitory computer-readable medium, such as memory, that are executable by a processing device to perform the functions and operations described herein. Accordingly, although not illustrated in FIG. **3**, the system **300** may further including a non-transitory computer-readable medium, a processing device, and/or other hardware.

The system **300** may be configured to receive a software program **312** generally including high-level software code. The high-level software code of the software program **312** may generally include software code in a human-readable format, such as text. For instance, the high-level software code of the software program **312** may be written in any one of various types of software programming languages, including, but not limited to, Perl, C, C++, C#, Java, JavaScript, Python, Ruby, assembly language, Fortran, COBOL, SQL, and PHP. The software program **312** may be received from a software editor or from some other source.

The compiler **306** may be configured to receive the software program **312** and to compile it into an intermediate representation **314**. Compiling the software program **312** may generally include parsing the software program **312**, determining whether the parsed software program **312** is syntactically correct and translating the syntactically correct and parsed software program **312** into the intermediate representation **314**. The intermediate representation may generally include software code in a machine-readable format, including, but not limited to, byte code, object code, machine code, virtual instructions, LLVM, and other intermediate representations of machine code.

The assertion instrumentation module **308** may be configured to receive the intermediate representation **314** and to instrument the intermediate representation. More particularly, the assertion instrumentation module **308** may be configured to find one or more instructions in the intermediate representation **314** that each match a corresponding pattern in a corresponding check pattern **316**. The assertion instrumentation module **308** may be further configured to generate an instrumented intermediate representation **318** in which the matched instructions are each modified according to an action specified in the corresponding check pattern **316**. Additional details regarding the check patterns **316** are described below.

The symbolic execution module **310** may be configured to receive the instrumented intermediate representation **318** from the assertion instrumentation module **308** and to symbolically execute the instrumented intermediate representation **318**. In some embodiments, the instrumented intermediate representation **318** may be in symbolic form and thus ready for symbolic execution by the symbolic execution module **310**. Alternately, the symbolic execution module **310** may translate the instrumented intermediate representation **318** into symbolic form before or currently with the symbolic execution of the instrumented intermediate representation.

By symbolically executing the instrumented intermediate representation **318**, the symbolic execution module **310** may analyze a portion of, a majority of, or all of the paths within the instrumented intermediate representation **318**. Based on the analysis of the paths within the instrumented intermediate representation **318**, the symbolic execution module **310** may be configured to identify errors within the instrumented intermediate representation **318**. The errors may include logical errors, accessing of illegal memory locations such as null pointer access, uninitialized pointers, divide by zero, out-of-bounds memory access, memory leaks where memory is allocated but never de-allocated, freeing unallocated memory, among others, as well as user-defined errors. The identified errors may be collected and output in a report **320**. In some embodiments, the report **320** may be presented to a user, e.g., a programmer, that has developed and/or is testing the software program **312**. For example, the report **320** or a portion thereof may be displayed in a status window of a software editor.

As indicated above, each of the check patterns **316** may include both a pattern and an action. In general, the pattern defines a relationship between two or more arguments while the action specifies a condition. The action may additionally specify a replacement instruction to substitute for an instruction in the intermediate representation **314** when the instruc-

tion includes two or more arguments having the relationship specified by the pattern and the condition is satisfied.

FIG. **4** illustrates various example check patterns **400** that may be implemented in the system **300** of FIG. **3**, arranged in accordance with at least one embodiment described herein. The check patterns **400** include check patterns **400**A-**400**D.

The check pattern **400**A may be configured to check for null pointer access. Accordingly, the check pattern **400**A includes a pattern, "store %1, %2," that defines a relationship between the arguments %1 and %2. In the check pattern **400**A, the relationship includes storing the argument %1 in memory at the argument %2. The check pattern **400**A also includes an action that specifies both a condition, "if (%2==0)," and a replacement instruction % i including an error report call "call report_null_ptr_access." Alternately or additionally, the replacement instruction may include both the condition and the error report call where any generic arguments, e.g., %1, %2, which merely serve as placeholders in the replacement instruction, are filled by the corresponding specific arguments used in the matching instruction. Replacing the matching instruction with the replacement instruction for this and other check patterns allows for symbolic execution of a resulting instrumented intermediate representation in which symbolic execution of a replacement instruction including a call to a specific error report, such as "call report_null_ptr_access" in this example, reports the particular error for inclusion in a resulting report, such as the report **320** of FIG. **3**. For example, reporting the particular error for inclusion in the resulting report may include reporting the type of the error based on the called error report and/or reporting a corresponding line of the software program, of the intermediate representation, and/or of the instrumented intermediate representation that caused the error.

The check pattern **400**B may be configured to check for divide-by-zero errors. The check pattern **400**B includes a pattern, "%3=fdiv %1, %2," that defines a relationship between the arguments %1, %2, and %3. The relationship in the check pattern **400**B includes the argument %1 being divided by the argument %2 to generate the argument %3. The check pattern **400**B also includes an action that specifies both a condition, "if (%2==0)," and a replacement instruction % i including an error report call "call report_div_by_zero." Alternately or additionally, the replacement instruction may include both the condition and the error report call where any generic arguments, e.g., %1, %2, %3, which merely serve as placeholders in the replacement instruction, are filled by the corresponding specific arguments used in the matching instruction.

The check patterns **400**A and **400**B are examples of check patterns that may be used according to embodiments described herein to detect common or known errors including, respectively, null-pointer-access errors and divide-by-zero errors. Examples of common or known errors that may be detected using an appropriate check pattern as described herein may include, but are not limited to, logical errors, accessing of illegal memory locations such as null pointer access, uninitialized pointers, divide by zero, out-of-bounds memory access, memory leaks where memory is allocated but never de-allocated, freeing unallocated memory, among others.

Alternately or additionally, check patterns may be used according to embodiments described herein to detect user-defined errors. Check patterns **400**C and **400**D are examples of check patterns that may be used to detect user-defined errors. In particular, the check pattern **400**C may be used to detect whether a range of computation result is less than a threshold value, and the check pattern **400**D may be used to detect whether a part of code is executed less than a threshold number of times. Other check patterns may be defined and used to detect other user-defined errors.

A more detailed explanation of the check patterns **400**C and **400**D will now be provided by way of illustration. The check pattern **400**C includes a pattern, "%3=(add|sub|mul) %1, %2," that defines a relationship between the arguments %1, %2, and %3. The relationship in the check pattern **400**C includes the argument %2 being added to, subtracted from, or multiplied by the argument %1 to generate the argument %3. The check pattern **400**C also includes an action that specifies both a condition, "if (%3>100)," and a replacement instruction % i including an error report call "call report_out_of_range." Alternately or additionally, the replacement instruction may include both the condition and the error report call where any generic arguments, e.g., %1, %2, %3, which merely serve as placeholders in the replacement instruction, are filled by the corresponding specific arguments used in the matching instruction. Thus, the check pattern **400**C allows a user to detect whether a range of computation result is less than the threshold value of 100 in this example.

The check pattern **400**D includes the same pattern as the check pattern **400**C, which has already been described. The check pattern **400**D also includes an action that specifies both a condition, "if (user_count>=10)," and a replacement instruction % i including "call report_many_executions." Alternately or additionally, the replacement instruction may include both the condition and the error report call where any generic arguments, e.g., %1, %2, %3, which merely serve as placeholders in the replacement instruction, are filled by the corresponding specific arguments used in the matching instruction. Thus, the check pattern **400**D allows a user to detect whether a part of code is executed less than the threshold number of times of 10 in this example.

Each of the check patterns **400** of FIG. **4** includes a single pattern, such as "store %1, %2" in check pattern **400**A, "%3=fdiv %1, %2" in check pattern **400**B, and "%3=(add|sub|mul) %1, %2" in check patterns **400**C and **400**D. Alternately, any given check pattern may include multiple patterns that have to be matched by instructions in an intermediate representation of a software program before evaluating a corresponding condition specified in an action of the check pattern. In these and other embodiments, the multiple patterns may be separated by semicolons or other suitable character, or may otherwise be distinguished from each other. The following three lines are examples of three patterns that may be included all in the same check pattern:

%1=load %2;
%3=(add|sub|mul) %1, %4; and
store %3, %5.

The foregoing patterns are provided by way of illustration only and should not be construed to limit the embodiments described herein. For example, a check pattern with multiple patterns may include as few as two patterns, or three or more patterns. Moreover, each of the patterns may include the same patterns described above and/or any other desired pattern.

Additionally, each of the check patterns **400** of FIG. **4** includes a single replacement instruction % i. Alternately or additionally, one or more check patterns may include multiple replacement instructions % i1, % i2, . . . , % iN.

FIG. **5** schematically illustrates a process flow **500** for analyzing software programs using a symbolic execution based dynamic checker (hereinafter "checker"), arranged in accordance with at least one embodiment described herein. The process flow **500** will be described in the context of the checker **302** of FIG. **3**.

The checker **302** receives a software program **502**, which is an example implementation of the software program **312** of FIG. **3**. The compiler **306** may compile the software program **502** into an intermediate representation **504**, which is an example implementation of the intermediate representation **314** of FIG. **3**. The assertion instrumentation module **308** receives the intermediate representation **504**, and additionally receives one or more check patterns **506**, which are an example implementation of the check patterns **316** of FIG. **3**.

As illustrated in FIG. **5**, the check patterns **506** include a first check pattern **508** for detecting null-pointer-access errors and a second check pattern **510** for detecting divide-by-zero errors. The first check pattern **508** includes a pattern **508**A of "store %1, %2" and the second check pattern includes a pattern **510**A of "%3=fdiv %1, %2." Accordingly, the assertion instrumentation module **308** searches the intermediate representation **504** for any instructions that match either or both of the patterns **508**A, **510**A.

In the illustrated embodiment, the assertion instrumentation module **308** finds an instruction **504**A in the intermediate representation **504** that matches the pattern **508**A. Accordingly, the assertion instrumentation module **308** evaluates whether a condition **508**B specified in an action of the pattern **508**A is satisfied by an appropriate one or more of the arguments in the instruction **504**A. In particular, in the illustrated embodiment, the assertion instrumentation module **308** evaluates whether the second argument, or % ptr, in the instruction **504**A is equal to zero. If the condition **508**B is not satisfied, the assertion instrumentation module **308** may search for other instructions in the intermediate representation **504** that match the same or other patterns. Because line 2 of the intermediate representation **504** assigns % ptr a value of zero, however, the condition **508**B is satisfied.

Thus, the assertion instrumentation module **308** generates an instrumented intermediate representation **512** in which the instruction **504**A is modified according to an action specified in the check pattern **508**. More particularly, in the illustrated example, the instruction **504**A is modified by replacing it in the instrumented intermediate representation **512** with a replacement instruction specified in the action of the check pattern **508**, the replacement instruction including both the condition **508**B and an error report call **508**C, as denoted at **512**A (hereinafter "text **512**A") in the instrumented intermediate representation **512**. As illustrated in FIG. **5**, the text **512**A includes the replacement instruction specified in the action of the pattern **508**A where the argument, or placeholder, %2 of the condition included in the replacement instructions is filled by the corresponding specific argument, or % ptr, used in the instruction **504**A.

FIG. **6** is a flowchart of an example method **600** of analyzing a software program **602** using a symbolic execution based dynamic checker (hereinafter "checker"), arranged in accordance with at least one embodiment described herein. The method **600** in some embodiments is performed by the checker, such as the checker **202** or **302** of FIG. **2** or **3**. Although illustrated as discrete blocks, various blocks may be divided into additional blocks, combined into fewer blocks, or eliminated, depending on the desired implementation. The method **600** may receive both the software program **602** and one or more check patterns **604** as inputs.

The method **600** may begin at block **606** in which a software program is compiled into an intermediate representation.

At block **608**, an instruction is found in the intermediate representation that matches a pattern in one of the check patterns **604**. Prior to finding the instruction that matches the pattern, the method **600** may generally include searching the intermediate representation for instructions that match one or more patterns in one or more corresponding ones of the check patterns **604**.

At block **610**, an instrumented intermediate representation is generated in which the instruction is modified according to an action specified in the corresponding one of the check patterns **604**. In these and other embodiments, generating an instrumented intermediate representation in which the instruction is modified according to an action specified in the check pattern may include replacing the instruction in the intermediate representation with a replacement instruction included in the check pattern. Moreover, as mentioned above, the pattern may define a relationship between two or more arguments. The action may specify a condition and a replacement instruction to substitute for the instruction in the intermediate representation when the instruction includes two or more arguments having the relationship specified by the pattern and the condition is satisfied.

At block **612**, the instrumented intermediate representation is symbolically executed.

At block **614**, a report **616** is generated based on the symbolic execution of the instrumented intermediate representation. The report may indicate one or more errors within the software program **602**.

Accordingly, some embodiments described herein may allow detectable defect types for a symbolic execution based dynamic checker to be programmed by instrumenting an intermediate representation. Alternately or additionally, some embodiments described herein may represent detectable defect types in pairs of a pattern and a corresponding action.

One skilled in the art will appreciate that, for this and other processes and methods disclosed herein, the functions performed in the processes and methods may be implemented in differing order. Furthermore, the outlined steps and operations are only provided as examples, and some of the steps and operations may be optional, combined into fewer steps and operations, or expanded into additional steps and operations without detracting from the essence of the disclosed embodiments.

For example, the method **600** may further include searching the intermediate representation for instructions that match any of multiple patterns, each of the patterns being included in a corresponding one of multiple check patterns. For each instruction that matches a corresponding one of the patterns, the corresponding instructions from the intermediate representation may be modified according to an action specified in a corresponding one of the check patterns. Additionally, prior to searching the intermediate representation for instructions that match any of the patterns, user input may be received that is effective to select at least a first check pattern from an available set of check patterns to include as one of the multiple check patterns. The method may further include, prior to receiving the user input effective to select at least the first check pattern, receiving user input effective to define the first check pattern. Accordingly, some embodiments described herein allow a user to define check patterns for detecting specific defects and/or selecting one or more check patterns from a database or other repository of check patterns that are considered when analyzing a software program.

Some embodiments described herein include an article of manufacture such as a non-transitory computer-readable medium having computer instructions stored thereon that are executable by a processing device to perform one or more of the operations included in the method **600** of FIG. **6**, such as the operations illustrated by blocks **606**, **608**, **610**, **612**, and/or **614** in FIG. **6**, and/or variations thereof. The non-transitory

computer-readable medium and the processing device may be included in the system **300** of FIG. **3**, for example.

FIG. **7** is a block diagram illustrating an example computing device **700** that is arranged for analyzing a software program using a symbolic execution based dynamic checker (hereinafter "checker") **726**, in accordance with at least one embodiment described herein. The computing device **700** may be included in or correspond to the system **300** of FIG. **3**, for example. In a basic configuration **702**, the computing device **700** typically includes one or more processors **704** and a system memory **706**. A memory bus **708** may be used for communicating between the processor **704** and the system memory **706**.

Depending on the desired configuration, the processor **704** may be of any type including, but not limited to, a microprocessor (UP), a controller, a microcontroller (UC), a central processing unit (CPU), a digital signal processor (DSP), any combination thereof, or other suitable processing device. The processor **704** may include one or more levels of caching, such as a level one cache **710** and a level two cache **712**, a processor core **714**, and registers **716**. An example processor core **714** may include an arithmetic logic unit (ALU), a floating point unit (FPU), a DSP core, or any combination thereof. An example memory controller **718** may also be used with the processor **704**, or in some implementations the memory controller **718** may be an internal part of the processor **704**.

Depending on the desired configuration, the system memory **706** may be of any type including, but not limited to, volatile memory (such as RAM), non-volatile memory (such as ROM, flash memory, etc.), or any combination thereof. The system memory **706** may include an OS **720**, one or more applications **722**, and program data **724**. The application **722** may include the checker **726** that is arranged to perform one or more of the operations or functions as described herein, including operations for analyzing a software program as described with respect to the method **600** of FIG. **6**. The program data **724** may include a test target and check pattern(s) **728**. The test target may include a software program that is being analyzed by the checker **726**, for instance. The test target and check pattern(s) **728** may be analyzed and/or used as described above to detect errors in the test target. In some embodiments, the application **722** may be arranged to operate with the program data **724** on the OS **720** such that implementations of methods of analyzing a software program such as the method **600** of FIG. **6** may be provided as described herein.

The computing device **700** may have additional features or functionality, and additional interfaces to facilitate communications between the basic configuration **702** and other devices and interfaces. For example, a bus/interface controller **730** may be used to facilitate communications between the basic configuration **702** and one or more data storage devices **732** via a storage interface bus **734**. The data storage devices **732** may be removable storage devices **736**, non-removable storage devices **738**, or a combination thereof. Examples of removable storage and non-removable storage devices include magnetic disk devices such as flexible disk drives and hard-disk drives (HDD), optical disk drives such as compact disk (CD) drives or digital versatile disk (DVD) drives, solid state drives (SSD), and tape drives to name a few. Example computer storage media may include volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information, such as computer-readable instructions, data structures, program modules, or other data.

The system memory **706**, removable storage devices **736** and non-removable storage devices **738** are examples of non-transitory computer-readable media. Non-transitory computer-readable media include, but are not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, or any other non-transitory medium which may be used to store the desired information and which may be accessed by the computing device **700**. Any such non-transitory computer-readable media may be part of the computing device **700**.

The computing device **700** may also include an interface bus **740** for facilitating communication from various interface devices (e.g., output devices **742**, peripheral interfaces **744**, and communication devices **746**) to the basic configuration **702** via the bus/interface controller **730**. Example output devices **742** include a graphics processing unit **748** and an audio processing unit **750**, which may be configured to communicate to various external devices such as a display or speakers via one or more A/V ports **752**. Example peripheral interfaces **744** include a serial interface controller **754** or a parallel interface controller **756**, which may be configured to communicate with external devices such as input devices (e.g., keyboard, mouse, pen, voice input device, touch input device, etc.) or other peripheral devices (e.g., printer, scanner, etc.) via one or more I/O ports **758**. An example communication device **746** includes a network controller **760**, which may be arranged to facilitate communications with one or more other computing devices **762** over a network communication link via one or more communication ports **764**.

The network communication link may be one example of a communication media. Communication media may typically be embodied by computer-readable instructions, data structures, program modules, or other data in a modulated data signal, such as a carrier wave or other transport mechanism, and may include any information delivery media. A "modulated data signal" may be a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media may include wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, radio frequency (RF), microwave, infrared (IR), and other wireless media. The term "computer-readable media" as used herein may include both storage media and communication media.

The computing device **700** may be implemented as a portion of a small-form factor portable (or mobile) electronic device such as a cell phone, a personal data assistant (PDA), a personal media player device, a wireless web-watch device, a personal headset device, an application-specific device, or a hybrid device that includes any of the above functions. The computing device **700** may also be implemented as a personal computer, including both laptop computer and non-laptop computer configurations.

All examples and conditional language recited herein are intended for pedagogical objects to aid the reader in understanding the invention and the concepts contributed by the inventor to furthering the art, and are to be construed as being without limitation to such specifically-recited examples and conditions. Although embodiments of the present inventions have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. A processor-implemented method of analyzing a software program, the method comprising:

compiling a software program into an intermediate representation;

finding an instruction in the intermediate representation that matches a pattern in a check pattern;

generating an instrumented intermediate representation in which the instruction is modified according to an action specified in the check pattern by replacing the instruction in the intermediate representation with a replacement instruction included in the check pattern, the replacement instruction including a call to an error report; and

symbolically executing the instrumented intermediate representation.

2. The processor-implemented method of claim **1**, wherein:

the pattern defines a relationship between two or more arguments; and

the action specifies a condition and the replacement instruction to substitute for the instruction in the intermediate representation when:

the instruction includes two or more arguments having the relationship specified by the pattern; and

the condition is satisfied.

3. The processor-implemented method of claim **2**, wherein:

the two or more arguments include a first argument and a second argument;

the pattern includes the first argument being stored in memory at the second argument;

the condition includes the second argument being equal to zero;

the replacement instruction includes the call to the error report; and

the error report comprises a null-pointer-access report.

4. The processor-implemented method of claim **2**, wherein:

the two or more arguments include a first argument, a second argument, and a third argument;

the pattern includes dividing the first argument by the second argument to generate the third argument;

the condition includes the second argument being equal to zero;

the replacement instruction includes the call to the error report; and

the error report comprises a divide-by-zero report.

5. The processor-implemented method of claim **2**, wherein the condition includes a condition defined by a user, the replacement instruction includes the call to the error report, and the error report comprises a report defined by the user.

6. The processor-implemented method of claim **1**, further comprising generating a report based on the symbolic execution of the instrumented intermediate representation, the report indicating one or more errors within the software program.

7. The processor-implemented method of claim **1**, further comprising:

searching the intermediate representation for instructions that match any of a plurality of patterns, each of the plurality of patterns being included in a corresponding one of a plurality of check patterns;

for each instruction that matches a corresponding one of the plurality of patterns, modifying the corresponding instruction from the intermediate representation according to an action specified in a corresponding one of the plurality of check patterns; and

prior to searching the intermediate representation for instructions that match any of the plurality of patterns, receiving user input effective to select at least a first check pattern from an available set of check patterns to include as one of the plurality of check patterns.

8. The processor-implemented method of claim **7**, further comprising, prior to receiving user input effective to select at least the first check pattern, receiving user input effective to define the first check pattern.

9. A system for analyzing a software program, the system comprising:

a processing device;

a non-transitory computer-readable medium having stored thereon:

a compiler executable by the processing device to compile a software program into an intermediate representation;

an assertion instrumentation module executable by the processing device to:

find an instruction in the intermediate representation that matches a pattern in a check pattern; and

generate an instrumented intermediate representation in which the instruction is modified according to an action specified in the check pattern by replacing the instruction in the intermediate representation with a replacement instruction included in the check pattern, the replacement instruction including a call to an error report; and

a symbolic execution module executable by the processing device to symbolically execute the instrumented intermediate representation.

10. The system of claim **9**, wherein:

the pattern defines a relationship between two or more arguments; and

the action specifies a condition and the replacement instruction to substitute for the instruction in the intermediate representation when:

the instruction includes two or more arguments having the relationship specified by the pattern; and

the condition is satisfied.

11. The system of claim **10**, wherein:

the two or more arguments include a first argument and a second argument;

the pattern includes the first argument being stored in memory at the second argument;

the condition includes the second argument being equal to zero;

the replacement instruction includes the call to the error report; and

the error report comprises a null-pointer-access report.

12. The system of claim **10**, wherein:

the two or more arguments include a first argument, a second argument, and a third argument;

the pattern includes dividing the first argument by the second argument to generate the third argument;

the condition includes the second argument being equal to zero;

the replacement instruction includes the call to the error report; and

the error report comprises a divide-by-zero report.

13. A non-transitory computer-readable medium having computer instructions stored thereon that are executable by a processing device to perform operations for analyzing a software program, the operations comprising:

compiling a software program into an intermediate representation;

finding an instruction in the intermediate representation that matches a pattern in a check pattern;

generating an instrumented intermediate representation in which the instruction is modified according to an action specified in the check pattern by replacing the instruction in the intermediate representation with a replacement instruction included in the check pattern, the replacement instruction including a call to an error report; and

symbolically executing the instrumented intermediate representation.

14. The non-transitory computer-readable medium of claim **13**, the operations further comprising generating a report based on the symbolic execution of the instrumented intermediate representation, the report indicating one or more errors within the software program.

15. The non-transitory computer-readable medium of claim **13**, the operations further comprising:

searching the intermediate representation for instructions that match any of a plurality of patterns, each of the plurality of patterns being included in a corresponding one of a plurality of check patterns;

for each instruction that matches a corresponding one of the plurality of patterns, modifying the corresponding instruction from the intermediate representation according to an action specified in a corresponding one of the plurality of check patterns; and

prior to searching the intermediate representation for instructions that match any of the plurality of patterns, receiving user input effective to select at least a first check pattern from an available set of check patterns to include as one of the plurality of check patterns.

16. The non-transitory computer-readable medium of claim **15**, the operations further comprising, prior to receiving user input effective to select at least the first check pattern, receiving user input effective to define the first check pattern.

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